# AN OPTIMAL FORAGING ANALYSIS OF PREHISTORIC SHELLFISH COLLECTING ON SAN CLEMENTE ISLAND, CALIFORNIA

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ABSTRACT.—The subsistence yield of black abalones *(Haliotis cracherodii)* and black turban snails *(Tegula funebralis)* was estimated within prehistoric aboriginal shell middens dated 250–2830 B.P. on San Clemente Island, California. Abalones were the key element of the aboriginal shellfish economy, but consumption of the smaller turban snails increased with depletion of abalones in a pattern that conforms to an optimal foraging model of predation.

RESUMEN.—El rendimiento de abalón negro *(Haliotis cracherodii)* y caracol de turbante negro *(Tegula funebralis)* para la subsistencia de las poblaciones indígenas fue estimado en concheros prehistóricos (250 a 2830 años antes del presente, datados con carbono radioactivo) en la Isla de San Clemente, California. Los abalones fueron el elemento clave en la economía aborigen de mariscos, pero el consumo de los caracoles de turbante, más pequeños, aumentó con el agotamiento de los abalones en un patrón que concuerda con un modelo de depredación como forrajeo óptimo.

RESUME.—Des traces de présence d'haliotides noires *(Haliotis cracherodii)* et d'escargots noirs à turban *(Tegula funebralis)* ont été découvertes au sein de vestiges résiduels préhistoriques de coquillages aborigènes (250 à 2830 années radio-carbones avant le temps présent) sur l'île de San Clemente, en California. Les haliotides constituaient l'élément principal de l'économie de coquillages aborigènes, mais la consommation des escargots à turban, bien plus petits, s'est accrue au fur et à mesure de la disparition des haliotides selon une progression conforme à un modèle optimal de ravages causés par des prédateurs.

Marine gastropod species were important subsistence resources among the aboriginal peoples of the southern California Channel Islands. Two species, the black abalone *(Haliotis cracherodii* Leach, 1814) and the black turban snail *(Tegula funebralis* A. Adams, 1855), are the focus of the present discussion. Abalone shells are a conspicuous component of prehistoric middens (domestic refuse deposits) on the Channel Islands. Beads, ornaments, fishhooks, containers, and other artifacts were manufactured from abalone shells. Despite this presence, recon-struction of the subsistence role of abalones and other shellfish species remains a relatively poorly developed area of investigation. Reconstructions usually estimate food yields based upon shell weight or MNI (minimum number of individuals) figures. Frequently, such estimates do not reflect the possibility that several species may have been utilized in shifting patterns of exploitation over

the time interval represented by a midden. This situation is surprising when one considers that the role of shellfishing by maritime hunter-gatherers is currently undergoing reexamination in many quarters. Recent archaeological and ethnographic studies have demonstrated the important role that shellfishing may play within a variety of economic adaptations. Consideration of biological characteristics of shellfish species, combined with appropriate analytical methods, reveal dynamic patterns of aboriginal shellfish collecting on San Clemente Island, southern California.[1]

## ABALONE AND TEGULA BIOLOGY

Abalones are large, herbivorous marine snails that inhabit many regions of the world. They require rock surfaces, where they attach themselves with a large, muscular "foot." Thus attached, they are protected by a thick univalve shell from predators and other hazards while grazing on floating kelp fragments. Species are readily differentiated based upon shell morphology. Water drawn through the gills is expelled through a series of prominent respiratory pores arrayed along the shell, the number and characteristics of which also vary by species (Howorth 1988:38-44). Abalone species occupy much of the Pacific Coast of North America, including California (Morris 1966:52), as well as Australia, New Zealand, and elsewhere.

Four species occur in significant frequencies within archaeological deposits of southern California. The three largest of these species generally occupy the subtidal zone; i.e., rocky substrates that remain submerged even during the lowest tides. Although these species vary in size and specific habitat requirements, they all inhabit substantially similar environments. Among the subtidal forms is the largest species in the world, the red abalone *(Haliotis rufescens)* with a shell length approaching 300 mm and a soft-tissue weight of as much as 3 lbs (1.36 kg; Morris et. al. 1980:232; Ault 1985:4). The green *(H. fulgens)* and pink *(H. corrugata)* abalones reach a maximum length of about 250 mm (Ault 1985:4; Morris et. al. 1980:234-235). All the subtidal species inhabit a depth gradient from the intertidal zone to at least 165 m for the red abalone, 18 m for the green abalone, and 50 m for the pink abalone. In cooler waters, such as found north of Point Conception in California, red abalone and other species may be found in the intertidal zone. The majority of individuals of subtidal species tend, however, to occur most frequently between about 6 m and 24 m (Cox 1960:386-390; Ault 1985:15-16). A number of factors appear to affect preferred depth, including algal production, habitat that offers protection to juvenile abalones, the presence of predators such as the sea otter, and water temperature (Ault 1985:15-16; Morris et al. 1980:232).

Generally, subtidal species can only be obtained by diving. Where these species exist in comparatively shallow water, diving can produce large harvests. The relatively large size of the subtidal forms may compensate for the effort involved in diving. It has also been suggested that red abalone may have been intertidal during the early and mid-Holocene (i.e., around 5000-7000 B.P.; Glassow et al. 1988:70), when periods of sea temperature cooler than at present may

have existed in the California Bight (southeastward bend of the California coast below Point Conception). A spatulate prying device (aboriginal forms were made of bone or wood) is generally required to break the animal's extremely powerful grip on its rocky perch.

Water temperature has a major impact on the life-cycle of subtidal abalones, with each species exhibiting a particular tolerance range. The red abalone, for example, feeds between 7° and 20°C, but the thermal optimum for the species is between 14° and 18°C (Ault 1985:15). Water temperature requirements are probably more important in relation to paleoenvironmental reconstruction than assessment of dietary yield. Use of abalone species as indicators of past marine environmental regimes is a topic important to archaeological research in southern California, but beyond the scope of this paper (Walker and Snethkamp 1984:7; Glassow 1977:19; Glassow et al. 1988:70; Raab and Yatsko 1990a, 1990b).

During abalone reproduction, eggs and sperm are released into the water, where fertilization occurs. After fertilization, larvae begin grazing within a few days. Initial growth of all species is relatively rapid, reaching about 20-30 mm within the first year (Morris et. al 1980:232-237; Ault 1985:5-6). After reaching the juvenile stage, abalone grow more slowly, adding a few millimeters length each year. Abalone appear to reach sexual maturity within 3-5 years, and it is thought that few individuals live longer than 20 years (Morris et al. 1980:232-237). All abalone species are slow growing organisms with few defenses against human predators. Consequently, their numbers are rapidly reduced under sustained collecting, and considerable time is required for a population to recover.

The black abalone (*Haliotis cracherodii*), the species of interest in the present discussion, is largely an intertidal form. These organisms frequently are exposed during low tides on rocks, where they can exist in large numbers. These abalone may be particularly at risk from human predators because they are easily harvested without diving. Individuals of this species reach a maximum size of about 200 mm, but few individuals exceed 150 mm. Black abalone have temperature requirements similar to red abalone (Ault 1985:15). Black abalone, as in the case of other abalones, requires several years to reach maximum size; about 2 years to reach 55 mm, then growing about 4 mm a year after reaching 90 mm in length (Ricketts et al. 1985:245). During early phases of growth, abalones seek the protection of rock crevices to avoid predators. Individuals become *emergent* upon reaching a length of 75-100 mm; i.e., they venture onto exposed rock surfaces in search of food (Ault 1985:6).

The black turban snail (*Tegula funebralis*) is common to abundant on open rocky surfaces of the intertidal habitats that support the black abalone (Morris et al. 1980:253). The smooth, rounded to conical shell may reach a diameter of 30 mm, though many individuals are much smaller. At low tide *T. funebralis* is sedentary, and hundreds of individuals often aggregate in rock crevices. Locomotion is achieved with a muscular foot in the same fashion as other marine gastropods. Tegula are herbivores that eat many species of algae, including microscopic films and kelp fragments (Morris et al. 1980:253). They may reach 20-30 years of age, and thus may have a lifespan longer than any other gastropod (Morris et al. 1980:254). Like black abalone, black turban snails are readily exploited by terrestrial predators during low tide.

# RETHINKING THE LOWLY SHELLFISH

As compared to terrestrial resources, shellfish often have been characterized as "emergency" or low-yield foods of comparatively minor importance. Osborn (1977) argues, for example, that marine environments are generally less productive per unit area than terrestrial environments. He suggests that human populations tend to relegate marine resources to a lower order of importance if terrestrial resources are available. The open ocean is less productive than many terrestrial ecosystems (Pianka 1974:48), but Yesner (1980) and Erlandson (1988, 1991) point out that this fact is misleading in view of the comparatively high productivity of certain coastal habitats.

Shellfish collecting has long been regarded as unimpressive as a gauge of cultural "advancement." Uhle (1907:31), for example, dismissed the prehistoric inhabitants of the Emoryville shell mounds in California as representative of the "lower classes of society" owing to their dependence on shellfish:

> The manner of procuring the essentials of life by collecting shells in itself indicates a low form of human existence. In all parts of the world, even today, people may be seen by the shore at low water collecting for food the shells uncovered by the retreating tide; and although under changed conditions of life they raise shellmounds, these people always belong to the lower classes of society, and lead in this manner a primitive as well as simple life.

Meehan (1982), in her excellent ethnographic study of shellfishing in Australia, points out the many misconceptions and biases that have worked against an informed understanding of shellfish economies. Fortunately, the significance of shellfish in maritime adaptations recently has received more objective attention. Sanger (1988:91), for instance, notes the important role of shellfish in settlement patterning and subsistence in the northeastern United States:

> Shellfishing, obviously an important aspect of the Gulf of Maine maritime adaptation, required only the use of hands to pluck mussels from rocks, or "pick" clams through their siphon holes... Briefly, shellfish, although frequently belittled in the literature as gross contributors to the overall caloric component of shell midden sites, may have constituted the primary motivation for site selection and abandonment. They constituted a reliable, if not spectacular, food source, and it would have been possible to over-exploit resources in the kinds of intertidal flats commonly found associated with habitation sites. A pattern of brief occupation, followed by movement to another site, may help to explain the presence of nearly 2,000 known shell midden sites an the coast of Maine that have survived erosion due to a submerging shoreline.

Erlandson (1988:107), in evaluating the role of shellfish in the prehistoric maritime economy of southern California, makes a similar point:

> ... I have tried to counter previous assertions that shellfish exploitation is universally inefficient subsistence strategy by demonstrating that, under

a variety of conditions, shellfish can serve as an efficient and sustained protein yield. This hypothesis has been supported with experimental data on protein yields for shellfish collecting, an archaeological example from coastal California, and a reexamination of two previous models of shellfish exploitation.

Recent evidence suggests that coastal populations of early Holocene (7000–10,000 B.P.) southern California subsisted on a diet in which calories were supplied to a large extent by hard seeds, and substantial protein was provided by shellfish (Erlandson 1991).

Relying on both ethnographic and archaeological data, Davidson (1984) demonstrates the important role played by shellfishing in the aboriginal settlement-subsistence systems around Palliser Bay, New Zealand. Virtually in a class by itself, the study by Meehan (1982) of aboriginal shellfishing in Australia provides detailed data on the ecology, social organization, nutritional yield, and integration with larger economic systems of shellfish economics.

The result of these investigations is increasing recognition of the distinctive and important roles of shellfishing. This recognition should prompt archaeologists to go beyond the cursory treatment of shellfish remains that have been characteristic of many research efforts of the past:

> ... the economics of shellfish exploitation should be evaluated in relation to the productivity and reliability of other resource alternatives, including factors such as the nutritional role played by various resources, the technological investment in resource acquisition, non-food payoffs, the availability of various foods to different age and gender groups within a society, seasonal limitations on the availability of different resources, and differential storability (Erlandson 1989:15).

## SAN CLEMENTE ISLAND

San Clemente Island, 58 sq mi (148 sq km) in extent, is the southern-most of the eight Channel Islands found off the southern California coast (Fig. 1), and lies 48 mi from the nearest landfall on the mainland. In historical times the island was occupied by the island Gabrielino Indians (Johnson 1988; Bean and Smith 1978). Although the island's culture history is poorly understood at present, recent archaeological studies indicate a human occupation of nearly 10,000 years (Salls 1988:353–362). The island contains evidence of some of the oldest maritime cultural adaptations on the Pacific coast of North America (Raab and Yatsko 1990a, 1990b).

During the Miocene, the island was thrust above the ocean by block faulting. This process, combined with rising and lowering ocean levels during the Pleistocene, has formed at least 18 wave-cut terraces on the island's west shore (Olmsted 1958). Active terrace-cutting produces a broad, rocky shelf of the type that characterizes most of the island's west shore today. Rocky intertidal, shallow reef, and kelpbed habitats support a rich marine ecosystem characteristic of rocky substrates. A number of gastropod species, including abalones, inhabit this zone.
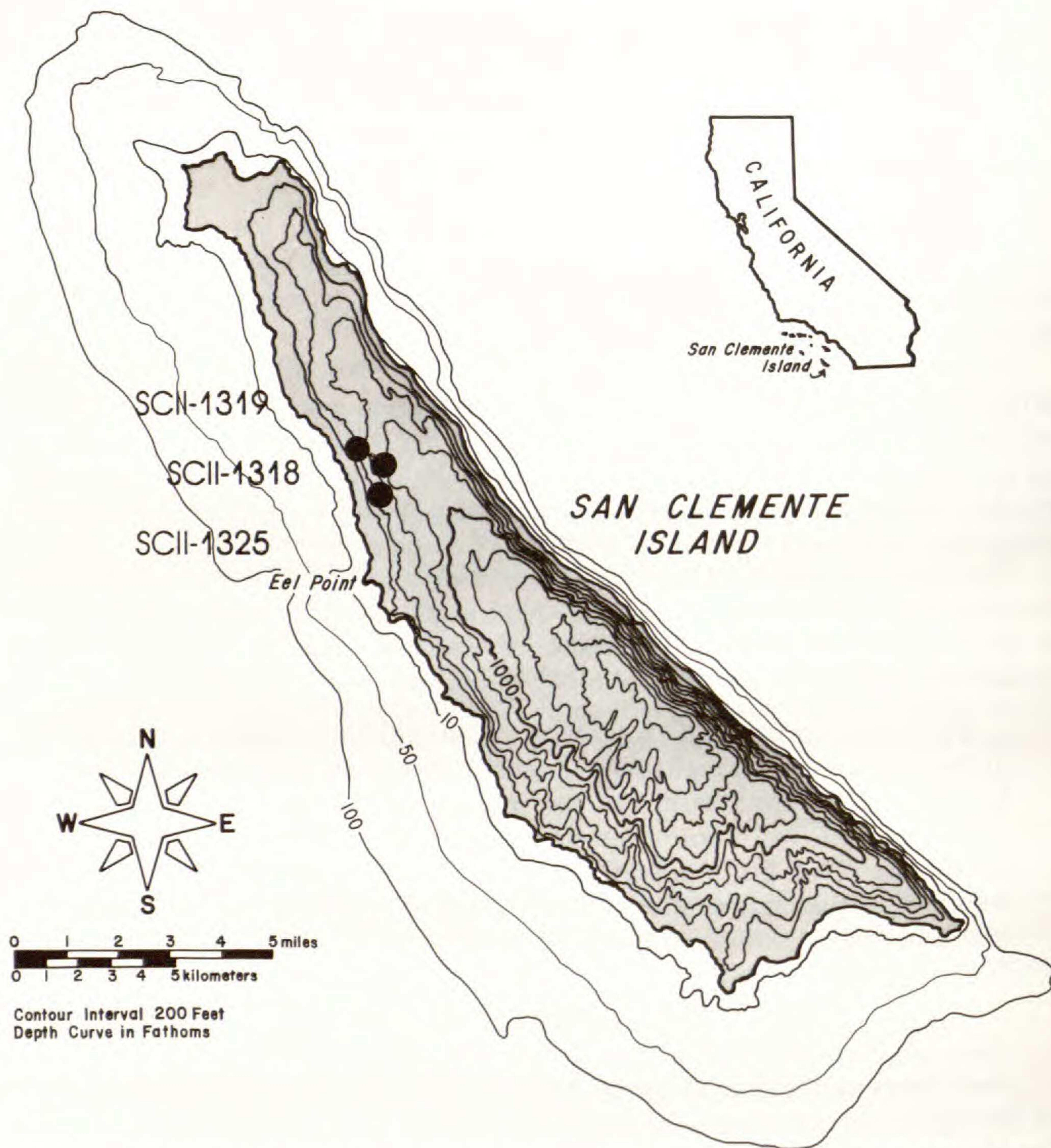
FIG. 1.—San Clemente Island, California. Archaeological sites SCII–1318, SCII–1319, SCII–1325, and the Eel Point site (SCII–43) are indicated.

Significantly, marine terraces have the greatest number of archaeological sites per sq km of any physiographic zone on the island; frequently 200–300 per sq km (Yatsko 1987a, 1987b). Most sites are relatively small, discrete shell midden sites, some of which have apparent house floor depressions. The site in Fig. 2 is characteristic of the small, shallow shell middens found on the coastal terraces of San Clemente Island. The Eel Point site complex (SCII–43), covering many acres and producing the oldest dated cultural component on the island (9700 B.P.; Salls 1988:353–369),is found within this zone.

Three coastal midden sites, SCII–1318, SCII–1319, and SCII–1325, were partially excavated. These sites are located on a high marine terrace, approximately 300 m above sea level, on the central west side of the island (Fig. 1). Sites SCII–1318

FIG. 2.—Midden sites on the west shore of San Clemente Island are characteristicly small, spatially discrete shell middens. The broken line indicates limits of midden (site SA–61; photo by Andrew Yatsko).

and SCII–1319 were selected for excavation because they appeared typical of hundreds of others in the area, and were comparatively easy to reach from an existing road. Both sites are black, ashy midden deposits containing abundant marine shell and burned rock deposits. All three sites were systematically tested with a soil auger, 10 cm in diameter, in order to estimate their subsurface character and extent. Based on the auger data, excavation units were placed to obtain samples of midden from the deepest to the shallowest portions of the deposits at a site.

Site SCII–1318 is approximately 24 m (north-south) by 16 m (east-west), with a total volume of approximately 41 m³. Four 1 m by 1 m excavation units were placed within this site; one near the periphery, two in the deepest midden deposits, and one between the periphery and the two deep pits. All excavation units were dug to a depth of 30 cm below surface, for a total of 1.20 m³ of excavated midden matrix.

Site SCII-1319 proved to be nearly circular in outline, 21 m in diameter, with a volume of approximately 76 m$^3$. Four 1 m by 1 m excavation units were excavated within the site; two near the center and deepest portion of the deposits, one at the periphery, and one between the center and periphery. Three excavation units were dug to a depth of 40 cm, and one unit reached a depth of 30 cm before encountering culturally sterile sediments, for a total of 1.5 m$^3$ of excavated midden matrix.

Site SCII-1325 was selected to salvage information from a midden damaged by past military activities. A military "foxhole" had been dug into the center of the midden, exposing a 60-cm-deep midden stratum. The depth of this site is unusual for coastal midden sites in this area. We examined this stratum in the area of the site damaged by the foxhole. A portion of the wall of the foxhole was cleaned and a vertical profile established. A 1 m by 1 m unit was excavated into the midden deposit from the cleaned profile. This site was approximately 30 m in diameter, with the excavation unit located near the center of the site. The site contains about 212 m$^3$ of midden. The excavation unit was dug to a depth of 60 cm, yielding a total volume of 0.6 m$^3$ of excavated midden matrix. Despite efforts to clear away midden deposits disturbed by the excavation of the foxhole, variability in compaction of the midden matrix and other factors suggest a reversed stratigraphic sequence.

Two of these sites have been radiocarbon dated. However, these dates present difficulties that cannot be resolved within the scope of this paper. Paired samples of charcoal and shell were taken from each excavation level of the two sites ("arbitrary" 10-cm levels). Unfortunately, the dates of charcoal and shell samples from the same midden proveniences vary greatly; far beyond differences one might expect to result from the $^{14}$C "reservoir effect" (Stuiver et al. 1986). In radiocarbon years before present these dates are:

Site SCII-1318:

|           | Charcoal Dates          | Shell Dates             |
|-----------|-------------------------|-------------------------|
| 0–10 cm   | 250+/-50 (Beta–39148)   | 1560+/-60 (Beta–39143)  |
| 10–20 cm  | 350+/-50 (Beta–39146)   | 1777+/-50 (Beta–39145)  |

Site SCII-1319:

|           | Charcoal Dates          | Shell Dates             |
|-----------|-------------------------|-------------------------|
| 10–20 cm  | 240+/-50 (Beta–39148)   | 2160+/-50 (Beta–39147)  |
| 20–30 cm  | 300+/-70 (Beta–39150)   | 2830+/-50 (Beta–34149)  |

No time-diagnostic artifacts were found in the middens. Studies are in progress by the author to identify possible sources of errors in radiocarbon dating on San Clemente Island, but at present one can only safely conclude that the sites are of late Holocene age.

As noted above, excavation units were dug in 10-cm levels to culturally sterile sediments. All excavated midden was passed through 1/8" (5 mm) mesh screen. Material collected in the screen was sent to the lab where *all* recovered midden constituents were identified and weighed. The resulting data were entered into a computer data base. The sheer volume of shell and other materials to be

identified and recorded imposed a substantial analytical burden. Nearly 480 person-hours were required to analyze and record the 3.3 m3 of midden matrix recovered by our excavations.

Analysis identified a broad spectrum of subsistence remains. For purposes of analysis, however, emphasis was placed upon five classes of faunal remains which are useful indicators of a number of ecological and subsistence variables: abalone (*Haliotis*) shell, *Tegula* shell, sea urchin tests (hard body parts) and spines, sea mammal bone, and fish bone (Table 1). Most of the abalone shell from the middens was fragmentary. All specimens are black abalone (*H. cracherodii*), common to the island's rocky west shore. *Tegula funebralis*, the small black turban snail inhabiting the intertidal zone of the west shore (Hedgpeth and Hinton

TABLE 1.—Tabulation by weight (gm) of midden constituents, by stratigraphic levels, for sites SCII-1318, SCII-1319, and SCII-1325.

| | *Haliotis* | *Tegula* | Sea Urchin | Mammal Bone | Fish Bone | *Tegula/ Haliotis* Ratio |
|---|---|---|---|---|---|---|
| SCII-1318: | | | | | | |
| 0-10 cm | 151.29 | 1,409.70 | 0.07 | 1.04 | 4.0 | 9.3:1 |
| 10-20 cm | 415.67 | 2,656.8 | 0.05 | 5.53 | 5.86 | 6.4:1 |
| 20-30 cm | 411.83 | 1,579.04 | 0.13 | 12.77 | 3.13 | 3.8:1 |
| Totals: | 978.89 | 5,654.61 | 0.25 | 19.34 | 12.99 | |
| Site Percentage:[1] | 8.10 | 65.83 | 0.0029 | 0.23 | 0.15 | |
| SCII-1319: | | | | | | |
| 0-10 cm | 136.00 | 2,859.44 | 6.55 | 6.31 | 6.27 | 20.9:1 |
| 10-20 cm | 1,457.92 | 17,333.07 | 17.12 | 15.87 | 19.28 | 11.9:1 |
| 20-30 cm | 5,051.38 | 26,837.13 | 83.42 | 90.49 | 95.84 | 5.3:1 |
| 30-40 cm | 7,036.14 | 12,882.62 | 79.25 | 207.44 | 69.35 | 1.8:1 |
| Totals: | 13,682.04 | 59,912.26 | 186.35 | 320.11 | 190.74 | 1.8:1 |
| Site Percentage:[1] | 16.63 | 72.82 | 0.23 | 0.39 | 0.23 | |
| SCII-1325: | | | | | | |
| 0-10 cm | 157.55 | 1,864.11 | 1.92 | 6.65 | 22.93 | 11.8:1 |
| 10-20 cm | 689.65 | 6,533.00 | 6.09 | 10.28 | 62.01 | 9.5:1 |
| 20-30 cm | 965.94 | 6,675.00 | 3.10 | 75.10 | 37.96 | 6.9:1 |
| 30-40 cm | 590.79 | 5,085.00 | 11.35 | 17.87 | 17.07 | 8.6:1 |
| 40-50 cm | 572.64 | 2,885.00 | 10.87 | 34.35 | 7.83 | 5.0:1 |
| 50-60 cm | 68.04 | 289.58 | 0.83 | 00.00 | 0.85 | 4.3:1 |
| Totals: | 3,044.61 | 23,331.69 | 34.16 | 144.25 | 148.65 | |
| Site Percentage:[1] | 8.78 | 67.31 | 0.10 | 0.42 | 0.43 | |

[1]Percentages do not sum to 100% because these figures are not based on the total weight of all dietary elements and other midden constituents.

1961:24–25), contributed the largest proportion of shell to the middens. Sea urchin remains are of the purple sea urchin *(Strongylocentrotus purpuratus)*. It may be assumed that essentially all mammal bone was derived from sea mammals; the island has no indigenous mammals larger than the Channel Islands Fox *(Urocyon littoralis)*. There is no archaeological evidence on San Clemente Island indicating that this species was used for food. Fish bones frequently can be identified from the spines, vertebrae, syncranial bones, and other elements found in the middens. Table 1 presents the weight and percentage of the five classes of faunal remains by site and stratigraphic level.

The high proportion of tegula shell is striking. Table 1 shows that tegula shell ranges from 67.31% to 72.82% of all dietary elements by weight. Uncritical assessment of these figures may lead to unwarranted conclusions. One must approach reconstruction of prehistoric diet from midden remains with a number of cautions in mind. Among these is recognition that the sheer frequency or proportional representation of a species is not necessarily an accurate index of economic importance. Although a midden may contain only a few sea mammal bones, for example, the subsistence yield of this resource might have been greater than the combined yield of a more abundant faunal class such as shell.

Reconstruction of dietary yield from archaeological shell samples requires attention to several problems. The fragmentary nature of midden shells frequently frustrates the task of determining the MNI (minimum number of individuals) represented by a shell sample. Frequently, MNI must be estimated on the basis of shell weight. Estimates of this type must recognize that after deposition in a midden, shell may be transformed by physio-chemical processes. Leaching of carbonates may reduce the weight of shells (Kent 1988:9–16), with obvious implications for MNI figures based upon weight.

Tegula and black abalone shells, both fresh and midden specimens, were examined to estimate possible leaching effects, and to derive MNI estimates based upon shell weight. Comparison of the weight of fresh and midden shells of equal size shows that midden shells have lost approximately 3–4% of their weight, presumably as a result of the dissolution of carbonates from the latter. This estimate should be applied with caution, however, since leaching effects may vary with the age of sites.

A sample of 65 living tegula of various sizes was collected from a tide pool on San Clemente Island. These were boiled in water for 10 min to remove these small organisms from their shells. Although cooking may result in a slight reduction of flesh weight, it was assumed that this loss would be no greater than the loss caused by prizing the organisms out of broken shells. Weight of cooked flesh averaged 0.47 gm. Average shell weight was 2.59 gm. Applying a 4% reduction for shell leaching gives an estimated average weight for archaeological shell specimens of 2.49 gm. Using this average, 2,267 individual tegula are represented by the total weight of tegula shell in site SCII-1318 (Table 1). At an average flesh weight of 0.47 gm per organism, 2,267 tegula would yield 1,065.49 gm (2.34 lbs) of meat. Applying the same calculations, site SCII-1319 yields 24,061.15 organisms, producing 11,308.74 gm (24.92 lbs) of meat; site SCII–1325 yields 9,370.16 organisms, producing 4,403.97 gm (9.71 lbs) of meat.

As in the case of tegula shell, it is possible to estimate the meat yield of a sample of abalone shell. This estimate can be made by determining the MNI represented by the sample of midden shell, and the meat yield of this number of individuals. Once again, living populations afford a partial basis for yield estimates. Leighton and Boolootian (1963:237) provide two slightly different formulas for estimating the soft-tissue weight of the black abalone from shell length measurements. These data derive from studies at Point Dume and the Palos Verdes Peninsula, southern California. Both formulas were obtained from regression analyses of body weight on shell length. Reflecting slight differences in the size range of the two abalone populations, the Point Dume formula yields a fractionally more conservative estimate; i.e., body weight tends to be slightly less in relation to shell size when compared to the Palos Verdes population. Selecting the more conservative measure, the Point Dume formula is:

$$\log W = 3.465 \log L - 4.668$$

(W = soft-tissue weight [gm]; L = shell length [mm])

The formula is reported to have an error factor of +/-6% over a range of shell lengths from 50-120 mm. It is not clear why this formula was employed instead of standard allometric formulas (e.g., $Y = aX^b$, $\log Y = b(\log X) + \log a$), but Leighton and Boolootian's data offer one method for estimating meat yield from shell length.

Recent studies by the author and others of midden shells and living abalones on San Clemente Island are also useful for estimating meat yields. During 1990, information was collected on shell length and soft tissue weight of 111 living black abalones from three contiguous areas on the island's west shore.[2] Abalones of all sizes were taken from the intertidal zone in the order in which they were encountered. The shell length of each specimen was recorded, along with the weight of the foot and viscera (foot weight + viscera weight = total soft tissue weight). Information was also collected on abalone shell length and weight from middens.

Data from living specimens offer only a partial solution to the problem of fragmentary shells in middens. Estimates of abalone meat yield from midden remains involve several factors. Shell length data offer an approach to establishing MNI counts. Black abalone shells excavated from the sites discussed here ranged from about 50-130 mm, although few shells exceeded 80 mm. Unfortunately, no systematic measurements of shell lengths were made during excavation. Recently collected shell data, however, afford a means of characterizing abalone shell length in the island's midden sites.

Measurements of whole abalone shells are available from three archaeological sites on the island. Abalone measurements were taken recently at two midden sites, SCII-315 and SCII-310, on the west shore of San Clemente Island. At site SA61 (SCII-315), 51 whole specimens were recovered and measured, with a mean length of 59.8 mm and a standard deviation of 18.7 mm. At site SCII-310, 86 whole specimens were recovered with a mean length of 69.2 mm and a standard deviation of 14 mm. A third sample of shells was obtained from a refuse deposit within

a prehistoric pithouse at the Nursery site (SCII–1215; Salls and Raab 1991). This deposit yielded 111 shells with a mean length of 75.2 mm and a standard deviation of 18.3 mm. These three archaeological shell samples have a modal length of 70–80 mm.

For purposes of estimating meat yield of prehistoric specimens, a modal shell length of 75 mm seems reasonable. Using the Leighton and Boolootian (1963:237) formula presented earlier, a meat weight of 67.47 gm is obtained for a shell length of 75 mm. The author's study of living black abalone, however, produced a somewhat different result: average soft tissue weight for specimens ranging 70–79 mm (n = 6) was 40.92 gm. It may be appropriate, in this case, to use 40.92 gm as the average soft tissue weight of an abalone with a shell 75 mm long. This figure is derived empirically from an extant local population, and the formula presented by Leighton and Boolootian may tend to overestimate the soft-tissue weight of specimens below 100–120 mm. An estimate of total meat yield may be obtained by multiplying the 40.92 gm average body weight by the estimated MNI represented by a shell sample.

In order to estimate MNI, it is necessary to know the weight of a 75 mm long shell. Fifty-five abalone shells were collected by the author from deflating midden deposits at the Eel Point site (SCII–43) in order to obtain information on length and weight characteristics. Shells 70–80 mm long (n = 5) averaged 25 gm. A weight of 25 gm was therefore used to estimate the MNI represented in Table 1, and the number of specimens thus derived were multiplied by 40.92 gm (soft-tissue weight). Estimates of total meat yield for turban snails and abalone for each of the levels of the three midden sites are presented in Table 2.

Another factor to be considered here is whether the whole organism was eaten or, like modern consumers of abalone, prehistoric peoples ate only the muscular foot. Clearly, total dietary yield would vary, depending on the portion eaten. The present estimates are of *maximum possible meat yield;* i.e., consumption of all soft tissue. I am aware of at least one ethnographic instance in which all soft tissue was apparently consumed (Meehan 1982:5–6). There appears to be no nutritional basis for ruling out such a practice.

On the basis of meat yield, abalones appear to be the key shellfish component of the middens, although this conclusion might not be apparent from either casual observation of the middens themselves or examining the high percentages of tegula shell in Table 1. Of resources gathered in the intertidal zone, abalones have the greatest subsistence yield. Tegula were being intensively collected as well, making a secondary subsistence contribution. The importance of abalone procurement within the subsistence base may be examined in another fashion. A factor analysis (*Systat* statistical program, V. 3.0) of data presented in Table 1 creates a statistical model in which it is possible to estimate the influence of each faunal constituent on each of the other constituents. This procedure is a principal components analysis, which determines the total amount of variance explained by each of the faunal constituents (components) within Table 1. Variance estimates are derived from regression coefficients for all variables in Table 1. This analysis is helpful in determining which dietary components influence the values of others within the matrix. The results of this analysis are that the abalone component

TABLE 2.—Estimated total meat yield (gm) for *Tegula* and *Haliotis*.

| Site SCII–1318: | *Haliotis* | *Tegula* |
|---|---|---|
| 0–10 cm | 247.63 | 266.00 |
| 10–20 cm | 680.37 | 501.49 |
| 20–30 cm | 672.72 | 298.05 |
| Totals: | 1,600.72 | 1,065.54 |
| Site SCII–1319: | | |
| 0–10 cm | 222.60 | 539.73 |
| 10–20 cm | 2,386.32 | 3,271.70 |
| 20–30 cm | 8,268.10 | 5,065.64 |
| 30–40 cm | 11,516.75 | 2,431.66 |
| Totals: | 22,393.77 | 11,308.73 |
| Site SCII–1325: | | |
| 0–10 cm | 257.88 | 351.86 |
| 10–20 cm | 1,128.82 | 1,233.14 |
| 20–30 cm | 1,581.05 | 1,259.94 |
| 30–40 cm | 967.00 | 959.82 |
| 40–50 cm | 937.30 | 544.55 |
| 50–60 cm | 111.37 | 54.55 |
| Totals: | 4,983.42 | 4,403.86 |

always accounts for the greatest percentage of variance explained: 57.89% for site SCII–1318 (followed by tegula at 42.12%); 80.56% for site SCII–1319 (followed by tegula at 18.32%); and 61.96% for site SCII–1325 (followed by 21.23% for tegula). In other words, variation in the contents of the middens is most strongly correlated with the amount of abalone shell present. These data suggest that abalone collecting was particularly important in structuring the whole shellfish collecting pattern.

It is hardly surprising that abalones and tegula account for most of the variance in Table 1, given the fractional representation of the remaining midden constituents. It is interesting, however, that abalones account for the greatest percentage of variance explained, despite the fact that shell weights for tegula are higher than those of abalones. These data suggest that dietary remains from the samples examined are keyed in their variability to the amount of abalone shell in the middens. Despite the significant contribution of tegula to the subsistence base, abalone seem to play a pivotal role in structuring the subsistence pattern both as revealed by the factor analysis and the estimated meat yields.

## OPTIMAL FORAGING

The observed data conform well to an optimal foraging model of subsistence:

The range of foods eaten by different populations of animals or human hunter-gatherers depends both upon the "value" of available, edible resources ..."Value" may be defined as the net energy yield of a resource per unit of "handling time;" for human hunter-gatherers, the latter includes time devoted to the capture, retrieval and processing of different foods. The result is that most foragers take an optimal range of resources, or optimal dietary breadth ... When is a particular resource included in (added to) the optimal dietary breadth? This appears to depend primarily on the "value" of that item, and both the abundance and the value of more valuable resources ... Thus, the value (handling time) of an item is the major factor, and abundance a secondary factor, in determining the resources "selected" to constitute the optimal diet (Yesner 1981:150).

Moreover:

Large, carnivorous foragers, such as humans, tend to exploit their environments in a "fine-grained" fashion, encountering and exploiting resources in the proportions in which they actually occur ... Thus, for those species that are harvested, an optimal forager will take them in amounts representative of the biomass of that species in the (local) environment. In other words, while the spectrum of species eaten may not be a representative sample of all species available, among those that are eaten, harvested biomass should be proportional to that in the natural environment (Yesner 1981:150).

Although the present discussion focuses on the five midden constituents presented in Table 1, the middens actually contain a broad spectrum of food remains from the intertidal zone, albeit at quite low frequencies. We find remains of limpets, chitons, crabs, and birds, for example. The middens appear to contain essentially every edible tide pool species likely to have been taken by a "fine-grained" mode of foraging. For this reason it seems likely that the relative proportions of abalones and tegula in the middens reflect the availability of these species in the tide pool environment, an observation reinforced by the present intertidal ecology. The foraging strategy employed by the prehistoric tidepool gleaners appears to reflect the fact that, of all species available, only abalones and tegula could be collected in sufficient quantities to meet dietary needs.

The abalone is clearly the single most "valuable" species represented in the middens; i.e., this species would yield the greatest subsistence return in relation to the "handling time" involved in procurement. The black abalone, as discussed earlier, is a "meat package" of substantial size. This species, being an intertidal form, is also relatively easy to exploit; they are readily collected on rocks exposed during low tides. This food resource is also easily exhausted. Even a small group of foragers, given daily collecting trips, could quickly strip a sizable section of the shore of abalone. This suggests that the optimal dietary breadth was dynamic; i.e., was determined not only in relation to the types of food resources encountered in the tide pools, but also by the impact of the foragers themselves.

Any decrease in the availability of abalone would likely change the value of tegula in the dietary spectrum. These snails individually represent quite small food items; on this basis, their dietary value may appear to be minimal at best. On the basis of the optimal foraging model, however, their value as a food item would be determined in relation to their abundance, the availability of food items of higher value, and their handling cost. The imposing presence of tegula in the middens clearly indicates that they were abundant. In the event of an insufficient supply of higher value shellfish (abalone), their abundance alone may recommend tegula as a food item. The ease with which tegula may be obtained reduces their handling time, thus increasing their relative value. These snails are easily collected by hand in tide pools during low tide. Ease of procurement also means that most members of the population could participate in economic production without special skills or equipment. Significantly, children and the aged, persons otherwise marginal to the economy, can make significant contributions to the diet by collecting shellfish. Although nutritional data on tegula are lacking, as algae-consuming gastropods, it seems reasonable to assume that they would yield nutritional benefits on par with abalone (c.f. Erlandson 1988:104).

But what about the handling time involved in extracting food from such a small organism? At first this factor might seem to weigh against the dietary value of tegula. An interesting comparison can be made here to research by Yesner (1981:155) on prehistoric Aleut middens:

> In addition, there appears to have been selection among shellfish species. For example, while conch-type gastropods (periwinkles and whelks) are relatively abundant on the strand flat, comprising about twenty per cent of the shellfish biomass, they are practically non-existent in the middens, and there is no ethnographic evidence that they were ever significant dietary items. These species probably fall outside the optimal diet, owing to the large time and energy expenditure required for their processing (handling costs). They are smaller than other shellfish species, and picks would have been required to retrieve the individually small amount of (low calorie) meat from them.

From this perspective, it may be surprising that tegula were exploited at all. The midden evidence from San Clemente Island indicates, however, that other ways of handling small gastropods in a cost effective manner are available. Nearly all tegula shell from the middens has been crushed. Processed in this fashion, tegula do not need to be extracted as individual organisms. Instead, the crushed organisms are freed from their shells, and can be cooked in bulk. The result is a food product that can be obtained with relatively economical handling costs.

The intertidal ecosystem of San Clemente Island's west shore, then, offered certain resource potentials for shellfish exploitation. The fashion in which this ecosystem was utilized conforms well to an optimal foraging model of subsistence. Black abalone exploitation was the single most valuable component of the shellfish economy. Since this resource was easily depleted, however, the dietary breadth

was necessarily dynamic, with black turban snails collected in large quantities to supplement dwindling supplies of abalones. This pattern is indicated in the shifting ratios of tegula to abalone meat yield from the lower to the upper levels of the middens (Table 1).

If the conclusions presented here are correct, other aspects of the prehistoric ecosystem come into focus. Intensive collecting for food items within the intertidal zone, even by small human populations, easily has the capacity to exhaust the supply of species such as abalone and tegula. As noted earlier, Yatsko (1987a) has documented hundreds of shell midden sites of the kind described here on the coastal terraces of San Clemente Island. Frequent residential moves are perhaps the only means by which a hunting-and-gathering society can cope with the easily depleted resources of the intertidal zone on San Clemente Island. High mobility of this type could account for the thousands of small midden sites on the island's west shore. This is a settlement dynamic similar to that described by Sanger (1988:91).

The intensity of prehistoric abalone collecting on San Clemente Island is suggested by the modal size of midden specimens, which ranged between 70 and 80 mm. As noted earlier, abalones are emergent when they reach a length of 75–100 mm (Ault 1985:6); i.e., they leave the protection of rock crevices to forage for food on exposed surfaces. The midden specimens suggest that few postemergent abalones escaped human predators.

## CONCLUSIONS

Detailed analysis of aboriginal shell middens on San Clemente Island indicates that exploitation of shellfish species conforms well to predictions derived from an optimal foraging model of subsistence. Although these middens are composed largely of tegula shells, estimates of meat yield indicate that the black abalone provided the greatest proportion of food. A factor analysis shows that abalone shell weights best explain variance in the composition of the total shell assemblages. An aboriginal strategy of shellfish collecting is proposed in which an optimal dietary breadth responds dynamically to rapid depletion of abalones (highest value food source) through exploitation of tegula, a second rank but relatively low-cost food source.

## NOTES

[1]The research described here is part of a five-year cooperative research agreement between the Center for Public Archaeology, California State University, Northridge and the Natural Resources Office, North Island Naval Air Station, San Diego, California. San Clemente Island has been a Naval reservation since 1934. Prehistoric settlement patterning and human ecology are major topics addressed within a research design (Raab and Yatsko 1990a) being implemented through site surveys, specialized site testing programs, and archaeological field schools.

[2]The abalone studies were conducted under terms of a scientific collecting permit issued by the California State Department of Fish and Game. Field reports on several hundred living abalones on San Clemente Island were provided by Mr. Peter Haaker of the California State Department of Fish and Game.

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